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DUSTING MISCELLANEOUS SEEDS WITH RED COPPER OXIDE TO COMBAT DAMPING-OFF

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ABSTRACT

The range of possibility of the red copper oxide seed treatment for controlling damping-off caused mainly by *Pythium ultimum*, but to a lesser extent by *Rhizoctonia solani*, the injuriousness of the chemical, and the apparent stimulating effects have been studied in the greenhouse and field on 107 species and varieties of plants.

Damping-off control and injury by red copper oxide are largely specific for the plant, the fungus, and the conditions in question. It may be said tentatively that solonaceous plants, legumes, cucurbits, composits, spinach, and beets respond favorably to treatment. Crucifers, dianthus, asters, gaillardia, and hibiscus, among others, are likely to be injured. Lilium, allium, and corn were neither benefited nor greatly injured.

Injury is more apt to occur in the absence of soil organic matter or with insufficient soil moisture. Presoaking of certain seeds prior to treatment may also be favorable to injury.

In small dosages, red copper oxide sometimes accelerates emergence as well as elongation and deepens the color of such plants as cucurbits, peas, tomatoes, helichrysum, cosmos, and others. This may be due merely to protection against root disease.

Optimum dosage for spinach is about 2½ per cent of dust by weight; for beets, 6 per cent; but for cucurbits, peas, etc., about ¼ to ½ per cent. The specifications for red copper oxide as a fungicide are fairly well defined, but they are not yet being met by all manufacturers and jobbers. The dust should be bright, brick-red in color, which does not darken on standing; it should adhere strongly to white paper; it should fume when shaken in a vial; and it should pass thru a 325-mesh screen.

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INTRODUCTION

The proposal of the red copper oxide seed treatment for combating damping-off[2] has raised many questions concerning the range of its possibilities, its specifications for fungicidal purposes, and its manufacture to that end. The writers have investigated one or more of the questions somewhat independently, but have combined their results in the interests of unified presentation. Their primary object is to present the data obtained in exploring the range of possibility of red copper oxide as a seed treatment. The problem of specifications and manufacture will be presented only briefly as much of this is far from settled. A tentative ideal is set up, but this may have to be altered as knowledge of the subject expands.

Altho red copper oxide was used first in the greenhouse to promote better emergence of seedlings, perhaps it will eventually find its largest sphere of usefulness in the field as a means of stabilizing the stand or distribution of plants over the area seeded. Under present field procedure damping-off goes unchecked and during wet weather sometimes proves disastrous to the grower. Spinach and peas, for example, must be planted early in New York State if the crop is to have good quality and hence a good sale. That means planting in soil very liable to be wet and highly favorable to damping-off, with the result that stands are sometimes so poor as to necessitate replanting. By that time the season is too far advanced for the best growth of these crops.

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[2] Horsfall, James G. Red oxide of copper as a dust fungicide for combating damping-off by seed treatment. *New York State Agr. Exp. Sta. Bul. No. 615. 1932.*

A treatment like red copper oxide, then, that helps to eliminate the danger of losing a crop because of a poor stand is desirable, especially where the hazards of crop failure are too plentiful at best. Successful farming in periods of economic duress is only possible to the individual who lowers his cost of production per unit to a point where a profit may be effected. That is more feasible where some control of the emergence of the plants is possible.

The value of red copper oxide in a large way lies not in permitting two leaves of spinach to grow where only one grew before, but in eliminating one of the big uncertainties of crop production. Perhaps it will help in controlling production because it will tend to assure that a given quantity of spinach seed will produce on the average a given tonnage of spinach for the market. As one spinach canner expresses it, red copper oxide benefits his business because it smooths out one of the production difficulties that he always encounters. He has not been able heretofore to estimate well the tonnage that he could expect to can from each hundred pounds of spinach seed dispensed to his growers. Moreover, in the case of spinach, the uniformity of stands assured by the red copper oxide means that the leaves of each plant are supported by those of its neighbors so that they do not pick up as much dirt in harvesting and are not as liable to be rotted by soil organisms. This simplifies sorting in the factory which in turn helps to smooth out some of the peaks in the production load.

Tests have been made on the effect of the chemical on seeds of 107 species and varieties of plants in 243 experiments in the greenhouse or field, or both, and in several convenient localities, as shown in the tables. A cross index for each plant listed under its common and Latin name is appended.

Each plant could have been subjected, as some have, to treatment under a wide range of conditions as regards soil types, temperature, wetness, humus, or acidity, such as might be encountered in various localities, but this would have been an endless task. We know that response from the material varies with different local complexes, but it was scarcely feasible to attempt to encompass many of them. It seems more desirable to present the results now from a wide range of plants under a few sets of conditions than to withhold data from growers who might need such information. Therefore, let it be emphasized that this bulletin makes no pretense of completeness either as to the effectiveness of red copper oxide

or as to its injuriousness under all conditions. From data here presented we would recommend that red copper oxide be tried at first on a small scale by the prospective purchaser. We suggest this precaution because the success of any chemical used on plants for the control of disease rests upon a narrow margin of safety between the point where it will kill the causal fungus and the point where it will injure the plant. For various reasons this margin is narrower in some locations than in others.

NATURE OF DAMPING-OFF

It is well to mention briefly the nature of damping-off in order to construct a basis for understanding the manner in which red copper acts in controlling the disease. Growers generally have thought that damping-off is a disease of the above-ground seedling only. They have believed that plants are attacked only after they are up because at that time they may be seen to slump over and die. Not knowing that many poor stands are due to the damping-off that occurs before the plants emerge, they have attributed these failures to poor seeds. As a matter of fact, the mere breaking of the ground does not constitute a dividing line in the attacks of damping-off. A plant is just as tender and succulent and susceptible to damping-off, if not more so, before it emerges from the ground as afterward. This is why good seeds frequently come up so poorly and erroneously are considered inferior. In many cases decay sets in even before the tiny plantlet can poke its tip out of the broken seed coat. After the seedling once gets up into the sunlight, it rapidly becomes resistant to damping-off.

It is the below-ground or pre-emergence phase of damping-off that is most readily controlled by red copper oxide on the seeds. Each seed surrounded by a coating of the chemical is protected from rotting in the soil. The effect has been likened to the galvanizing action of the zinc covering applied to sheet iron to prevent rust.

It was gratifying to learn, however, that the above-ground or post-emergence phase of damping-off was likewise controlled to a considerable degree by treating the seed with red copper oxide. It is too much to expect that a small amount of the chemical added to a seed placed in the soil will prevent all the post-emergence damping-off, altho it is reasonably satisfactory for that purpose except under conditions more than usually favorable or with plants more than usually susceptible to damping-off.

MATERIALS AND METHODS

In working on such a practical problem the usual greenhouse procedure has been followed, taking only such added measures as were essential to assure data on the effectiveness of the material. An attempt was made to use only seed of high germinating capacity,[3] because red copper oxide does not make poor seeds better; it aids a good seed only in warding off the attacks of rot-producing molds, so that it can continue its growth unhampered In most cases the number of seeds planted was known, but for small seeds known weights or volumes of seed were sown. At all times the treated and untreated seed were grown side by side under approximately the same conditions during any one test Often in the case of greenhouse plants somewhat more than the normal quantity of water was applied in order to stimulate damping-off and thus give the treatment as drastic a test as possible. In commercial greenhouses, of course, local procedure was used. For most of the greenhouse tests composted soil naturally infested with the damping-off fungus (*Pythium ultimum*) was employed, but in some cases the plants were grown in muck soil. In such cases the fact is indicated in the tables. Field tests were made using regular planters and following customary field procedure.

EXPERIMENTAL RESULTS

SOIL NATURALLY INFESTED WITH *PYTHIUM ULTIMUM* AND OTHER DAMPING-OFF FUNGI

Greenhouse operators in New York State may grow flowers and vegetables together, or may specialize in one or the other. For the sake of convenience to these men, the data on ornamentals and vegetables are presented in separate tables listed by the name thought to be the most widely known. An index on page 37 lists all common and Latin names of the plants mentioned in the bulletin with citations to the place in the tables or text where the name appears.

EFFECT ON ORNAMENTALS IN THE GREENHOUSE

In Table 1 are listed the results obtained with 68 sorts of ornamentals tested in the greenhouse chiefly at Ithaca and Geneva. It is hardly necessary to discuss these plants separately. Suffice it

[3] The writers are indebted to the following seedsmen who kindly donated seed for some of the experimental work: W. Atlee Burpee Company, Henry A. Dreer, Ferry-Morse Seed Company, Joseph Harris Company, Inc., Jerome B. Rice Seed Company, and Rogers Brothers Company.

to say, that outstanding results in controlling damping-off were obtained with arabis, calendula, centaurea, cobaea, cockscomb, cosmos, eschscholtzia, gypsophila, helichrysum, heliopsis, larkspur, leptosiphon, lupine, African and French marigold, *Mesembryanthemum tricolor*, nasturtium, pansy, penstemon, pyrethrum, salpiglossis, salvia, snapdragon, stock, and sweet pea. Slight benefits could be seen on several others. On the other hand, several showed profound stunting or even reduction in stand. These included agrostemma, asters in a few trials, aubrietia, chrysanthemum, species of *Dianthus*, gaillardia, and hibiscus.

Altho the injury factor is discussed in detail on page 24, it should be mentioned here that in most cases the dosage of chemical was excessive. In any case, positive injury in these tests indicates that the seeds injured should be tested cautiously by growers. With varying environment, however, positive injury in one location does not necessarily indicate positive injury elsewhere. The same might be true in those cases where injury has thus far been lacking.

Edward Lehde, a florist in the Buffalo area, has kindly given us some of his observations on treated flower seeds. In 1933 and again in 1934 he treated all or nearly all the seeds sown and found favorable results with the following series of plants without apparent injury under his conditions, even when the red copper oxide was used in excess; aubrietia, azalea, carnation, clarkia, didiscus, flowering tobacco, geum, gilia, heliotrope, helichrysum, nemesia, petunia, phacelia, primula, rhododendron, salpiglossis, snapdragon, and viola. He felt that the effect of the red copper oxide was particularly striking on viola. He found beneficial stand increases, but slight stunting early in the season or with old seed of clarkia, dimorphotheca, gaillardia, larkspur, marigold, petunia, scabiosa, and zinnia. Later in the season or when new seed was used the delayed emergence was absent or only temporary. In fact Mr. Lehde thinks that delayed emergence when it does occur is so offset by the increased stands that it is of no practical importance.

Paul Galley, also of Buffalo, reports beneficial results or certainly no injury, altho checks were not planted, with asters, calendula, petunia, phlox, salpiglossis, salvia, scabiosa, snapdragon, stock, and verbena. He felt that his difficulty in earlier years in getting a stand, especially of petunia, phlox, salvia, and verbena was eased in 1933 by red copper oxide. These results were obtained in spite of the fact that the soil was being used for the second time.

Table 1.— Effect of Dusting Seeds with Red Copper Oxide on Emergence and on the Control of Damping-off of Various Ornamental Plants.

No.	Plants	Date sown in 1933	Location *a*	Seeds untreated: Emergence No. *b*	Seeds untreated: Emergence Per cent	Seeds untreated: Post emergence damping-off, per cent	Seeds dusted with red copper oxide: Dosage *c*	Seeds dusted with red copper oxide: Emergence No. *b*	Seeds dusted with red copper oxide: Emergence Per cent	Seeds dusted with red copper oxide: Post emergence damping-off, per cent	Remarks
1	Agrostemma	Mar. 30	I	160	....	......	E	159	....	......	Stunted
2	Anchusa	Mar. 30	I	21	....	......	E	26	....	......	
3	Arabis	Mar. 21	I	56	....	......	E	72	....	......	Stimulated
4	Arbor vitae	Feb. 9	N	64	....	......	S	86	....	......	
5	*Aster alpinus*	Mar. 28	I	44	....	......	S	46	....	......	
		Mar. 21	I	38	....	......	S	21	....	......	Evidently injured
6	Aster, China	Apr. 15	I	49	49	......	S	88	88	......	
7	Aster	Feb. 15	G	83*e*	....	27.5	S	55.7*e*	....	15.8	Slightly injured
		Oct. 9	G	8.5*f*	17.0	38.7	S	9.5*f*	19.0	2.5	
8	Aubrietia	Mar. 21	I	33	....	......	E	17	....	......	Evidently injured
9	Black-eyed susan	Apr. 15	I	46	....	......	E	43	....	......	
10	Calendula	Feb. 15	G	41.5*e*	83.0	0.0	S	39*e*	78	0.0	Emergence accelerated
		Oct. 9	G	14.5*f*	58.0	16.2	S	24.5*f*	98	0.0	
11	Campanula	Mar. 21	I	53	....	......	E	48	....	......	Slightly injured
		Feb. 9	N	......	....	......	S	......	....	......	Evidently benefited *h*
12	Centaurea	Feb. 15	G	16*d*	32	0.0	S	20*d*	40	0.0	
13	Chrysanthemum	Mar. 20	I	46	....	......	E	43	....	......	Stunted
14	Clarkia	Mar. 30	I	83	55	......	E	81	54	......	Stunted
15	Cobaea	Mar. 30	I	12	34	......	E	20	57	......	
16	Cockscomb	Mar. 30	I	45	....	......	E	86	....	......	Stimulated
17	Coffee berry	Apr. 3	I	20	61	......	E	17	56	......	
18	Coleus	Feb. 14	G	8*e*	....	19.5	S	13.3*e*	....	9.4	
19	Columbine	Mar. 21	I	23	....	......	E	26	....	......	
		Feb. 4	G	140	....	47.1	S	533	....	21.0	
		Feb. 9	N	......	....	......	S	......	....	......	Evidently benefited *h*
20	Cosmos	Mar. 30	N	15	....	......	E	17	....	......	
		Mar. 21	N	29	58	......	E	40	80	......	Stimulated

		Feb.	15	G	29.6*e*	59.3	......	S	38.7*e*	77.3	0.0	Stimulated
		Oct.	9	G	13.0	42.0	1.2	S	15.8	63.0	0.0	
21	Cynoglossum...........	Mar.	30	I	11	....	......	E	12	....	......	
22	Dahlia, var. Coltness Gem.	Mar.	28	I	16	53	......	E	24	80	......	
23	Dahlia, var. dwarf hybrid.	Mar.	28	I	28	80	......	E	24	69	......	
24	Dahlia sp...............	Feb.	15	G	15*e*	30	3.9	S	19*e*	38	2.3	
25	*Dianthus alpinus*........	Mar.	21	I	26	....	......	E	16	....	......	Severely injured
26	*D. barbatus*.............	Feb.	15	G	24.7	....	42.6	S	37.0	....	28.5	
27	*D. deltoides*.............	Mar.	21	I	46	....	......	E	24	....	......	Severely injured
28	*D. graniticus*............	Mar.	21	I	58	....	......	E	23	....	......	Severely injured
29	*D.* var. Sweet Wivelsfield.	Mar.	28	I	85	....	......	E	75	....	......	Slightly injured
30	Digitalis................	Feb.	9	N	......	....	......	S	......	....	......	Evidently benefited*h*
31	Eschscholtzia...........	Mar.	28	I	62	....	......	E	86	....	......	
32	Gaillardia..............	Mar.	30	I	43	....	......	E	39	....	......	Injured
33	Gypsophila.............	Feb.	28	I	5	2	......	E	70	35	......	
		Feb.	15	G	5*d*	....	71.2	S	14.3*d*	....	28.3	
34	Helichrysum............	Feb.	15	G	52.3*e*	....	25.2	S	204*e*	....	10.5	Stimulated
35	Heliopsis...............	Apr.	3	I	19	....	......	E	43	....	......	
36	Heliotrope..............	Mar.	28	I	80	....	......	E	96	....	......	Slightly injured
37	Hibiscus................	Feb.	4	G	36.7*e*	36.7	30.4	S	42.0*e*	42.0	0.0	
		Oct.	9	G	10.5*f*	42.0	0.0	S	4.0*f*	16.0	0.0	Evidently injured
38	Hollyhock..............	Feb.	4	G	14.5*f*	58.0	0.0	S	17.3*f*	69	0.0	
		Oct.	9	G	10.0*f*	40.0	3.3	S	13.6*f*	54.5	2.3	
39	Huckleberry, garden.....	Apr.	3	I	132	....	......	E	112	....	......	Slightly injured
40	Larkspur, annual........	Apr.	15	I	55	....	......	E	59	....	......	Slightly injured
41	Larkspur...............	Feb.	15	G	56.5	....	36.1	S	49.0	....	13.2	
		Feb.	9	N	......	....	......	S	......	....	......	Evidently benefited *h*
42	Leptosiphon............	Apr.	3	I	101	....	......	E	157	....	......	
43	*Lilium* spp.............	Feb.	4	G	......	....	......	S	......	....	......	Not benefited*h*
44	Lupine.................	Feb.	4	G	3.8	27.0	0.6	S	14.5	53.0	0.2	
		Oct.	9	G	3.3	13.0	0.0	S	11.3	45.0	0.0	
45	Marigold, African.......	Apr.	3	I	42	56	......	E	61	81	......	
		Apr.	15	I	12	24	......	E	27	54	......	
46	Marigold, French........	Apr.	15	I	51	64	......	E	70	87	......	
47	Martynia...............	Apr.	3	I	34	....	......	E	38	....	......	

a Letters indicate localities as follows: G, Geneva; I, Ithaca; M, Mineola; N, Newark.
b Equal number, weight, or volume of seed sown per flat or per row.
c Letters indicate dosages as follows: S, standard dosage, 1 teaspoonful per pound, or 2½ per cent; E, excess dosage.
d 2 replications. *e* 3 replications. *f* 4 replications. *g* 7 replications.
h Plants not counted.

TABLE 1.— *Concluded.*

No.	Plants	Date sown in 1933	Location *a*	Seeds untreated: Emergence No. *b*	Seeds untreated: Emergence Per cent	Seeds untreated: Post emergence damping-off, per cent	Seeds dusted with red copper oxide: Dosage *c*	Seeds dusted with red copper oxide: Emergence No. *b*	Seeds dusted with red copper oxide: Emergence Per cent	Seeds dusted with red copper oxide: Post emergence damping-off, per cent	Remarks
48	Mesembryanthemum.....	Apr. 3	I	43	57	......	E	68	91	......	
49	Nasturtium............	Mar. 28	I	21	52	......	E	32	80	......	
		Apr. 15	G	8*g*	52.5	0.0	S	11*g*	75	0.0	
50	Pansy..................	Apr. 3	I	64	85	......	E	66	88	......	
		Feb. 15	G	16.5*e*	58.0	12.7	S	17.7*e*	70.7	0.0	
51	Penstemon.............	Mar. 28	I	81	....	......	E	140	....	......	
52	Petunia................	Feb. 28	I	30	15	......	E	24	12	......	Poor seed
53	Phlox..................	Mar. 28	I	76	76	......	E	78	78	......	
54	*Phlox Drummondii*......	Feb. 15	G	10.7	21.3	47.2	S	17.0	34	16.2	
55	Pine, mugho............	Feb. 9	N	223	....	......	S	287	....	......	
56	Pine, Scotch...........	Feb. 9	N	1,569	....	......	S	1,410	....	......	
57	Poppy..................	Feb. 14	G	1,152	....	7.0	S	1,188	....	4.9	
58	Pyrethrum.............	Feb. 15	G	49.3*e*	....	41.6	S	83.0*e*	....	26.1	
59	Salpiglossis............	Mar. 21	I	6	24	......	E	18	72	......	
60	Salvia..................	Feb. 14	G	7.7	15.3	27.3	S	15.0	30	0.0	
61	Saxifraga...............	Apr. 15	I	21	....	......	E	22	....	......	
62	Snapdragon.............	Feb. 28	I	46	23	......	S	76	38	......	
63	Spruce, white..........	Feb. 9	N	837	....	......	S	851	....	......	
64	Stock..................	Feb. 28	I	53	26	......	E	77	38	......	
65	Sunflower..............	Mar. 28	I	34	94	......	E	31	86	......	
66	Sweet pea..............	Sept. 5	M	24	24	......	E	91	91	......	Stimulated
		Apr. 3	I	78	52	......	E	128	85	......	Stimulated
		Jan. 3	I	9	18	......	E	30	60	......	Stimulated
		Feb. 14	G	11.7*e*	58.3	0.0	S	14.0*e*	70	0.0	
67	Venidium...............	Apr. 3	I	16	53	......	E	24	80	......	
68	*Zinnia*.................	Apr. 3	I	18	7 1	......	E	21	84	......	

For footnotes see page 9.

EFFECT ON VEGETABLES IN THE GREENHOUSE

Table 2 contains the data obtained in the greenhouse on 37 sorts of vegetable crops, using muck and loam soil. These data are in addition to those published in Cornell Bulletin 566 and in Bulletin 615 of this Station (now out of print) showing beneficial response from cabbage, eggplant, pepper, tomato, spinach, and celery. The plants given in Table 2 need not be discussed separately, since specific cases can be referred to the table. The plants that seem to respond most favorably are garden beets, sugar beets, chard, cucumber, eggplant, lettuce, muskmelon, peas, pepper, spinach, squash, and tomato.

Fig. 1 shows an instance of the value of treating beet seed in the greenhouse. The first row is untreated and the second row treated. The other rows are treatments that are not pertinent here.

Fig. 1.—Increase in Stand of Detroit Dark Red Beet Seedlings Resulting from Treating the Seed with Red Copper Oxide.

The first row at the left and the last thin row on the right were sown from untreated seed. The second row and the thick row in the right background were sown from treated seed. See No. 3, Table 2, Jan. 13, 1933.

Several additional plants showed favorable response at one time or another, others showed little or no reaction, while still others showed injury at times. The crucifers, like broccoli, cabbage, cauli-

TABLE 2.— EFFECT OF DUSTING SEEDS WITH RED COPPER OXIDE ON EMERGENCE AND ON THE CONTROL OF POST-EMERGENCE DAMPING-OFF OF VARIOUS VEGETABLES.

No.	Plant	Date sown	Location *a*	Seeds untreated: Emergence			Seeds dusted with red copper oxide				Remarks
				Emergence No.*b*	Emergence Per cent	Post emergence damping-off, per cent	Dosage *c*	Emergence No.*b*	Emergence Per cent	Post emergence damping-off, per cent	
1	Beans, lima.........	Feb. 14, '33	G	2.5*d*	15.8	16.4	$\frac{1}{4}$–100	13.2*h*	88.1	0.0	Emergence accelerated
			G	16.5*d*	66.0	0.0	$\frac{1}{2}$–100	23.5*d*	94.0	0.0	Stunting
2	Beans, wax.........	Jan. 30, '33	I	32	64	......	....	33	66	......	Slightly retarded
3	Beets, garden.......	Jan. 15, '33	I*m*	29	29	......	....	100	100	......	
		May 16, '32	I	21*e*	21	0.0	....	43*e*	43	0.0	
		Jan. 13, '33	G	67.7*e*	....	13.8	....	192.0*e*	....	0.3	See Fig. 1
		Jan. 31, '33	G	33.5*f*	67.0	74.8	....	70.3*f*	141.5	14.3	
		Feb. 18, '33	G	100.5	50.3	37.2	....	210.0	105.0	8.8	
4	Beets, sugar........	May 17, '32	I*m*	68.0	68.0	39.7	....	222.5	222.5	33.7	
5	Broccoli............	Jan. 31, '33	G	52.3*e*	52.3	2.6	S	69.0*e*	69.0	0.5	Slightly stunted
		Oct. 9, '33	G	21.5*d*	43.0	4.7	S	23.5*d*	47.0	3.6	No injury
6	Cabbage, Chinese....	Mar. 24, '33	I	82.0	....	......	....	75.0	....	......	Slightly stunted
7	Cabbage...........	Nov. 6, '31	G	1,387*d*	41.9	38.8	E	1,720*d*	52.1	31.8	
		Jan. 31, '33	G	55.0*e*	55.0	3.8	S	65.3*e*	65.3	1.0	
		Feb. 18, '33	G	16.5*h*	33.0	......	S	16.4*h*	52.7	......	See Fig. 2
		Mar. 25, '33	G	25.9*h*	51.7	8.2	S	29.4*h*	58.7	2.3	
8	Cardoon............	Mar. 24, '33	I	17.2	34.0	......	....	14.0	28.0	......	Slightly stunted
9	Carrot.............	Mar. 27, '33	I	38.0*e*	38.0	......	....	57.7*e*	57.7	......	
		Jan. 15, '33	I*m*	36.0	36.0	......	....	58.0	58.0	......	
		Jan. 31, '33	G	129.5*g*	....	3.4	S	154.2*g*	....	0.9	
		Feb. 18, '33	G	1,118	....	4.4	S	1,668	....	1.9	Stimulated
		Mar. 25, '33	G	1,522	....	1.1	S	1,409	....	0.4	
10	Cauliflower.........	Jan. 31, '33	G	77*e*	77	7.8	S	80.7*e*	80.7	3.3	
		Oct. 9, '33	G	34	68	7.2	S	38	76.0	5.6	
11	Celery.............	May 12, '32	W*m*	18*d*	18	......	....	1.5*d*	1.5	......	Evidently injured
		May 17, '32	I*m*	78*d*	....	......	....	82*d*	....	......	
		Mar. 27, '33	I	76*e*	76	......	....	34*e*	34	......	Evidently injured

		Mar. 24, '33	I	141	....	......	....	178	....	......	No injury
		Jan. 31, '33	G	743*e*	....	1.7	S	672*e*	....	0.8	Slightly injured *k*
		Mar. 25, '33	G	......	....	......	....	......	....	......	Not benefited
12	Chard.............	Jan. 8, '32	W*m*	86.5*d*	86.5	......	....	144.5*d*	144.5	......	
13	Chicory...........	May 17, '32	I*m*	94.5*d*	94.5	4.8	S	93.5*d*	93.5	3.2	
		Feb. 14, '33	G	191*e*	....	8.7	S	201*e*	....	1.0	
14	Chives	Mar. 24, '33	I	55	....	......	....	65	....	......	
15	Corn..............	Jan. 30, '33	I	34	68	......	....	29	58	......	
16	Cucumber..........	May 12, '32	W*m*	17.3*e*	17.3	0.0	S	59.0*e*	59.0	0.0	
		Feb. 14, '33	G	13.7*e*	68.3	9.0	1–100	17.0*e*	85.0	0.0	Emergence accelerated
		Feb. 18, '33	G	9.3*d*	46.7	5.6	2–100	12.7*d*	63.3	0.0	
		Apr. 17, '33	G	14.0	28.0	7.1	½–100	44.0	88.0	0.0	
		Apr. 18, '33	G	15.0	30.0	......	½–100	33.0*f*	66.0	......	
17	Eggplant...........	May 17, '32	I	29.8*f*	29.8	5.0	....	57.0	57.0	9.3	
		Jan. 30, '33	I	18	18	......	....	62	62	......	
		Feb. 8, '33	G	86.5*f*	86.5	12.5	....	92.3*f*	92.3	4.0	
18	Endive.............	Feb. 4, '33	G	278*d*	....	0.6	S	255*d*	....	0.3	
		Mar. 25, '33	G	1,723	....	21.5	S	2,158	....	1.7	See Fig. 3
19	Kohlrabi...........	Jan. 31, '33	G	57.0	57.0	2.0	S	63.0	63.0	0.5	Mild stunting
20	Leek...............	Mar. 24, '33	I	55	....	......	....	42	....	......	Notably injured
21	Lettuce............	Mar. 27, '33	I	72	72	......	....	84	84	......	
		Mar. 27, '33	I	62.5	....	......	....	96.5	....	......	
		Feb. 4, '33	G	314	....	5.4	....	299	....	1.9	
		Mar. 25, '33	G	2,313	....	9.7	....	2,752	....	4.0	
22	Muskmelon.........	May 17, '33	I*m*	3.0	6.0	0.0	....	45.0	90.0	0.0	
		Jan. 31, '33	G	10.2*d*	42.7	1.5	S	23.0*d*	92.0	0.0	Stimulated
		Mar. 30, '33	G	16	32	0.0	½–100	49	98	0.0	Stimulated
23	Okra...............	Apr. 5, '33	G	11*h*	55.0	8.2	....	9.2*h*	45.8	1.7	Slightly stunted
24	Onion..............	Mar. 24, '33	I	43.0	....	......	....	30.0	....	......	Notably stunted
25	Parsley............	Mar. 24, '33	I	115	....	......	....	99	....	......	Moderately stunted
		Feb. 14, '33	G	167*e*	....	3.7	....	167*e*	....	2.3	Moderately stunted
		Mar. 25, '33	G	548	....	1.0	....	678	....	0.4	Moderately stunted
		Feb. —, '33	R*i*	272.5*e*	54.5	24.0	E	360*e*	72.0	6.9	No injury
26	Parsnip............	Feb. 4, '33	G	19*d*	76.0	23.9	S	22.5*d*	90.0	0.0	

a Letters indicate localities as follows: G, Geneva; I, Ithaca; R, Riverhead; W, Williamson.
b Equal number, weight, or volume of seed sown per flat or per row.
c Letters indicate dosages as follows: S, standard dosage, 2½ lbs. per 100 lbs. seed, or 1 teaspoonful per pound of seed; E, excess dosage.
d 2 replications. *e* 3 replications. *f* 4 replications. *g* 5 replications. *h* 6 replications.
i The writers are indebted to Dr. H. S. Cunningham for this reading.
k Plants not counted.
l Great benefit almost always observed in greenhouse and field. See Cornell Bul. No. 566.
m Tested on muck soil, otherwise on loam soil.

Table 2.— *Concluded.*

No.	Plant	Date sown	Location *a*	Seeds untreated: Emergence No.*b*	Seeds untreated: Emergence Per cent	Seeds untreated: Post emergence damping-off, per cent	Seeds dusted with red copper oxide: Dosage *c*	Seeds dusted with red copper oxide: Emergence No.*b*	Seeds dusted with red copper oxide: Emergence Per cent	Seeds dusted with red copper oxide: Post emergence damping-off, per cent	Remarks
27	Pea	May 17, '32	I*m*	25.5*d*	51.0	7.8	....	42.5*d*	85.0	0.6	
		May 16, '32	I	39.0*d*	78.0	......	....	40.0*d*	80.0	......	
		Jan. 15, '33	I	8.0	16.0	......	....	44.0	88.0	......	
		Apr. 1, '32	G	1.0*f*	2.8	......	E	20.5*f*	58.9	......	
		Apr. 15, '32	G	3.8*f*	10.7	......	E	24.0*f*	68.6	......	
		Apr. 7, '33	G	13	52	16.0	$\frac{1}{4}$–100	19.0	76.0	0.0	
		Mar. 22, '33	G	3	3	33.0	S	52	52	6.0	Stimulated
28	Pepper	Aug. 1, '32	W*m*	113.5	....	......	....	207	....	......	Generally benefited
		Jan. 30, '33	I	37	37	......	....	69	69	......	
29	Radish	May 12, '32	W*m*	49.3*e*	49.3	0.0	....	59.3*e*	59.3	1.1	
		Feb. 4, '33	G	82.5*h*	....	4.2	S	78.0*h*	....	0.0	Slightly injured
		Oct. 9, '33	G	34.5*f*	79.0	3.8	S	41.5*f*	83.0	0.6	No injury
30	Rhubarb	Mar. 24, '33	I	73	73	......	....	47	47	......	Evidently injured
31	Salsify	Feb. 4, '33	G	22*d*	88	0.0	S	23.5*d*	94.0	0.0	
32	Spinach	....	..	......	....	......	....	......	....	......	Always benefited *l*
33	Squash	Feb. 1, '33	I	26	52	......	....	37	73	......	
		Jan. 31, '33	G	26	28.9	0.0	S	67	74.5	0.0	See Fig. 6
		Feb. 11, '33	G	51	51	0.0	S	62	62	0.0	
34	Tobacco	Mar. 24, '33	I	......	....	......	....	......	....	......	Greatly benefited *k*
		Jan. 31, '33	G	......	....	......	....	......	....	......	Greatly benefited *k*
35	Tomato	Jan. 15, '33	I*m*	34	34	......	....	86	86	......	Generally benefited
		Mar. 27, '33	I	42.7*e*	42.7	......	....	90.7*e*	90.7	......	
		Aug. 1, '32	W*m*	182	....	......	....	306	....	......	
36	Turnip	May 12, '32	W*m*	56.7*e*	28.4	2.4	....	34.0*e*	17.0	5.9	
		Feb. 4, '33	G	80.0	80.0	12.1	S	77.3	77.3	3.3	Slightly injured
37	Watercress	Mar. 24, '33	I	......	....	......	....	......	....	......	Some benefit *k*

For footnotes see page 13.

flower, kohlrabi, and radish, were sometimes helped, as shown in Fig. 2, and sometimes were slightly stunted.

In nearly all cases with peas, response to treatment in the greenhouse was large, but occasionally slight stunting occurred altho

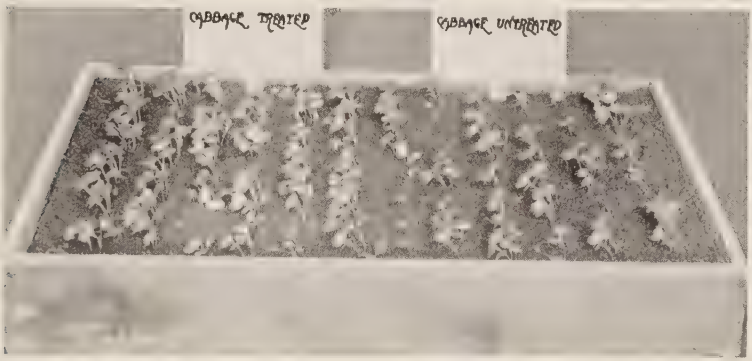

Fig. 2.—Increase in Stand of Enkhuizen Glory Cabbage Seedlings Resulting from Treating the Seed with Red Copper Oxide.

Fifty seeds per row. Left, treated; right, untreated. See No. 7, Table 2, Feb. 18, 1933.

sometimes apparent stimulation was observed. Probably lima beans should not be treated with red copper oxide on account of injury, despite the obvious stand increases that can be obtained. Lima beans injured as seedlings show the effects of the injury for a long time, perhaps for life.

Lettuce sometimes responds favorably to treatment with red copper oxide. Several growers in the Buffalo area report large differences in favor of treating lettuce, romaine, endive, and escarolle seeds. In our experience such marked benefit was seldom observed on either muck or loam soil, but a case of beneficial results on endive in the Station greenhouses appears in Fig. 3.

Eggplant and pepper almost always respond favorably to treatment with red copper oxide, altho, injury to pepper may ensue, as has been shown in Erie and Schenectady counties. Most growers, however, feel that peppers and eggplants are so difficult to grow that a slight amount of delayed emergence and early stunting are not sufficiently detrimental to offset the benefit due to increased

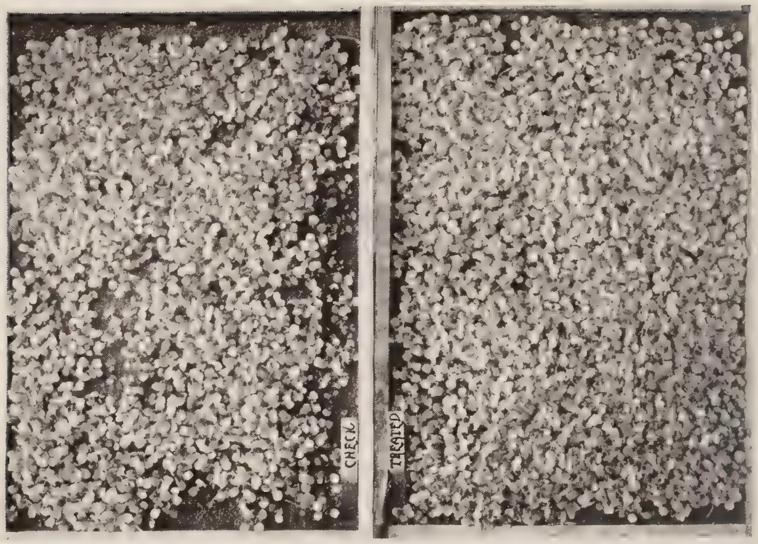

FIG. 3.—INCREASE IN STAND OF ENDIVE SEEDLINGS RESULTING FROM TREATING THE SEED WITH RED COPPER OXIDE.

Left, 1,723 plants from untreated seed; right, 2,158 plants from an equal volume of treated seeds. See No. 18, Table 2, March 25, 1933.

stand. The injurious effect seems to disappear with the first transplanting. The cucurbits, like squash, melon, and cucumber as a rule respond to treatment in the greenhouse or field when the dosage is not excessive, and probably they can be treated without fear. The same is true of spinach and tomatoes.

Celery on muck in the Williamson area usually was injured, especially where seed of only average vigor was employed; yet growers in Niagara County are using red copper oxide on celery seed with success on loam soil. They report excellent response even where the material is applied to wet seeds after they have been soaked and allowed to begin to sprout. This is an excellent illustration of the variability in response from red copper oxide and of the necessity of testing it in a locality where it is to be used.

Onions, leeks, and chives responded so poorly under the conditions tried that one is not encouraged to treat these generally.

EFFECT ON VEGETABLES IN THE FIELD

Damping-off may be just as prevalent in the field as in the greenhouse, especially when the weather is excessively wet. Several field tests on the value of red copper oxide in controlling damping-off have been made. The field records on spinach have already been presented.[4] These show that spinach responds exceedingly well to treatment under conditions that give poor stands of that crop. Reports from other spinach areas of the United States indicate that this response is widespread.

The stand records from 1933 field tests on several vegetables are presented in Table 3. Yield records were made from several of these, but on such a small scale that they are valuable only for showing the trends as given in Table 3. Since the early part of 1933 was generally favorable for emergence of seedlings from soil in the field, the untreated seedlings came up rather well, so that the treatments gave only small differences. Then in midsummer the soil was so dry in many fields that seeds could not obtain sufficient water to finish the process of germination, so that they died. In that case also differences were not pronounced. This was of particular importance in the case of carrots and beets which are sown at that time of year. Nevertheless, Table 3 shows that beets, squash, cucumbers, melons, lettuce, carrots, and salsify responded favorably to treatment; while beans, corn, and onions were not helped at all or were injured. Possibly under moister conditions or in different fields, these crops might have responded differently.

In the case of peas, favorable results on stands have been obtained, but in one or two cases there have been hints of injury. Accordingly data on this crop are being reserved pending further investigation. Extensive field tests are planned for 1934.

SOIL ARTIFICIALLY INFESTED WITH *RHIZOCTONIA SOLANI*

Rhizoctonia solani is frequently considered[5] not to be sensitive to copper toxicity, altho Alexander, Young, and Kiger[6] found that

[4] Pirone, P. P., Newhall, A. G., Stuart, W. W., Horsfall, J. G., and Harrison, A. L. Copper seed treatments for the control of damping-off of spinach. *Cornell University Agr. Exp. Sta. Bul. No. 566. 1933.*

[5] Wiant, J. S. The Rhizoctonia damping-off of conifers and its control by chemical treatment of the soil. *Cornell University Agr. Exp. Sta. Mem. No. 124. 1929.*

[6] Alexander, L. J., Young, H. C., and Kiger, C. M. The causes and control of damping-off of tomato seedlings. *Ohio Agr. Exp. Sta. Bul. No. 496. 1931.*

TABLE 3.— EFFECT OF DUSTING SEEDS WITH RED COPPER OXIDE ON THE EMERGENCE OF VARIOUS VEGETABLES IN THE FIELD.

No.	Plant	Cooperator	Locality	Seeds untreated		Seeds dusted with red copper oxide			Remarks
				Number of counts	Average number of plants in 10 ft. of row	Dosage	Number of counts	Average number of plants in 10 ft. of row	
1	Beans, Valentine stringless......	L. Gasper....	Geneva......	11	38.4	¼ to 100	4	31.4	
2	Beans, wax......	L. Gasper....	Geneva......	5	33.6	¼ to 100	4	36.0	
3	Beets, garden....	....	Williamson†..	3	34.3*	....	3	78.3*	
		....	Geneva......	......	48.1	Excess	......	32.2	Excessive injury, dry soil
		C. B. Sayre...	Geneva......	10	25.9	2½ to 100	......	42.8	Yield increased
		L. Gasper....	Geneva......	32	20.7	2 to 100	32	23.7	
		F. Cammett...	Stanley......	10	62.4	2½ to 100	10	79.3	
		J. Sundinski..	Seneca Castle.	10	47.2	2½ to 100	10	68.0	Hand seeder used
		J. Sundinski..	Seneca Castle.	10	77.4	2½ to 100	10	84.0	Grain drill used
		Alton Jones...	Aloquin......	10	37.3	2½ to 100	10	33.6	
		Ed Conroy...	Stanley......	10	48.5	2½ to 100	10	60.6	
		....	Geneva......	6	29.0	2 to 100	10	33.1	Shower after seeding, yield increased
4	Beets, sugar......	....	Williamson†..	3	47.0*	....	3	86.0*	
5	Carrots..........	....	Williamson†..	3	50.0*	....	3	60.0*	
		....	Williamson†..	2	17.5*	....	2	27.0*	
		....	Williamson†..	......	72.5	....	......	83.2	
		....	Williamson†..	......	43.2	....	......	54.7	
		....	Williamson...	......	33.3	....	......	40.5	
		....	Williamson...	......	44.0	....	......	37.6	
		....	Geneva......	6	65.7	2½ to 100	9	73.7	Yield increased

6	Corn, Golden Bantam..........	L. Gasper....	Geneva......	6	69.0	$\frac{1}{4}$ to 100	6	56.0	
		....	Geneva......	10	11.0	$\frac{1}{4}$ to 100	10	8.9	
		....	Geneva......	10	8.9	$\frac{1}{4}$ to 100	10	7.5	
		....	Geneva......	10	18.5	$\frac{1}{4}$ to 100	10	23.0	
7	Cucumber.......	....	Warsaw......	1	21.7*	....	1	33.3*	
		....	Geneva......	33	68.0*	2 to 100	33	73.0*	
8	Lettuce..........	....	Williamson†..	3	15.7*	....	3	41.7*	
9	Muskmelon......	....	Geneva......	12	46.0*	....	12	54.0*	
		....	Williamson†..	2	35.0	....	2	79.0	
10	Onion..........	....	Williamson†..	3	87.3	....	3	87.0	
11	Parsnip.........	....	Geneva......	4‡	......	....	......	......	
12	Peas...........	....	....	§	......	....	......	......	
13	Radish..........	....	Warsaw......	2	45.7*	....	2	57.7*	
14	Salsify..........	....	Geneva......	4	172.5	$2\frac{1}{2}$ to 100	4	181.5	
15	Squash..........	....	Williamson†..	2	72.0*	....	2	83.0*	Stimulation marked
		....	Geneva......	10	62.5*	....	10	85.0*	

* Actual percentage emergence instead of number of plants in 10 feet of row.
† Muck soil.
‡ Not counted. No difference noted.
§ Benefit marked but data reserved for future publicaton.

tomato seeds soaked in a copper sulfate solution came up better than checks when planted in soil artificially infested with Rhizoctonia. The results with the copper compounds, however, have been ascribed mainly to control of *Pythium ultimum*.[7] In Table 4 are given some data kindly supplied by M. C. Richards, Graduate Fellow in Plant Pathology, Cornell University, showing a decided response of several vegetables to red copper oxide when sown in three lots of soil infested with separate strains of Rhizoctonia. Carrots, lettuce, spinach, and tomatoes responded almost without fail, but celery was injured by treatment. It seems odd that the representative of the organic mercuries, Semesan, should not have given better results on Rhizoctonia control.

Too much emphasis should not be placed on this one test, altho the consistency of the data indicate that they are significant. Perhaps the discrepancy between the positive results in combating Rhizoctonia with copper and the usual belief that the fungus is not copper-sensitive lies in the fact that it is the cuprous instead of the usual cupric ion that is involved here.

TABLE 4.— EFFECT OF RED COPPER OXIDE AND SEMESAN ON EMERGENCE OF VARIOUS VEGETABLES FROM SOIL ARTIFICIALLY INFESTED WITH *Rhizoctonia solani*.

SEED TREATMENT	NUMBER OF SEEDLINGS OF VARIOUS VEGETABLES EMERGED AFTER 23 DAYS FROM 150 SEEDS PLANTED				
	Carrots	Celery	Lettuce	Spinach	Tomato
	Rhizoctonia with Micro-sclerotia				
Check	19	58	72	2	28
Red copper oxide	56	12	84	52	86
Semesan	34	45	136	8	23
	Rhizoctonia, Isolant No. 33				
Check	84	85	91	26	45
Red copper oxide	58	61	114	63	83
Semesan	38	71	109	11	51
	Rhizoctonia from Tulip				
Check	11	85	34	3	55
Red copper oxide	59	29	79	56	95
mesan	39	67	61	15	67
	Average for Three Strains				
	38.0	76.0	65.7	10.3	42.7
xide	57.7	34.0	92.3	57.0	88.0
	37.0	61.0	103.0	11.3	47.0

G. Dusting tomato seed with copper sulfate monohydrate -off. *New York State Agr. Exp. Sta. Tech. Bul.*

COMPARISON OF RED COPPER OXIDE WITH OTHER MATERIALS

The efficiency of red copper has been compared with other standard seed treatments, such as organic mercuries, bluestone soak, and copper sulfate monohydrate dust treatment. The last-named material was studied in detail at this Station as a seed treatment for damping-off control, but it was only a step in the progress of the research. It has now been completely superseded by red copper oxide because of the better adhesion and the generally more satisfactory results obtained with the oxide form of the copper. In a previous publication[8] considerable data were presented indicating that the red copper oxide treatment gave better stands of spinach on both muck and upland soils than the bluestone soak, copper carbonate, Semesan, or copper sulfate monohydrate powder.

Since the publication of the paper on spinach, comparable data on other vegetables indicate in general that the red copper oxide seed treatment is at least as good as any material tried thus far and is much cheaper than some. The experiments show that all seeds are not equally benefited and that no one material invariably gives better results than all other materials in repeated trials.

From the data given in Table 4 it appears that even for rhizoctonia red copper oxide is more effective than an organic mercury for spinach, tomato, and carrot, but less effective for celery and lettuce. These results again bear out the conclusion that damping-off control by red copper oxide is specific for the plant, the fungus, and the conditions in question.

Data from several tests have been averaged and presented graphically in Fig. 4A, in which are shown several plants that are seldom benefited by red copper oxide and are injured when soaked in a copper sulfate solution. In Fig. 4B are shown several plants found to be greatly benefited by fungicidal treatment of any sort. In these tests they responded somewhat better to the copper compounds than to organic mercury as represented by Semesan. Mr. William Kroemer, however, reports the results of an experiment on beets replicated 6 times in his greenhouse in January, 1934, showing an average emergence from the check, red copper oxide, and Semesan of 146, 174, and 197 plants, respectively, from 100 seed balls.

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[8] *Loc. cit.*

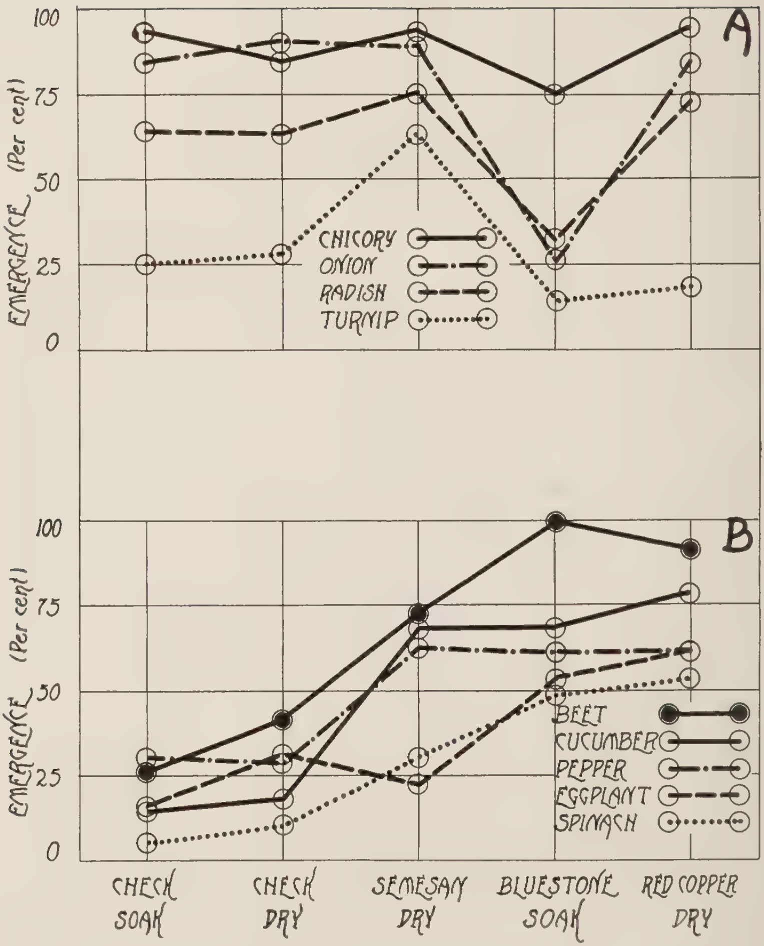

Fig. 4.—Graphic Comparison of Different Seed Treatments on Stand of Various Vegetables.

A, results with several plants seldom benefited by red copper oxide; B, results with plants that usually are benefited by fungicidal treatment.

DOSAGE OF RED COPPER OXIDE

Since red copper oxide may be injurious to plants at times, dosage studies should be conducted to ascertain the minimum dosage possible

in order to reduce this injury factor without curtailing effectiveness. Dosage studies also show the optimum amount of dust to use without waste. The dosage curve for red copper oxide on spinach already published served as the basis for establishing the standard dosage of 2½ per cent, or 1 teaspoonful per pound of seed. When dealing with a material to be applied to seeds sometimes in packet lots and sometimes in ton lots, dosage terminology becomes involved. For experimental purposes and for large amounts of seed, percentage by weight is satisfactory. Thus, the standard dosage could be used as 2½ pounds per 100 pounds of seed, 2½ ounces per 100 ounces, or 2½ grams per 100 grams, as the need arose. Similarly, fractions of 1 per cent by weight, as ½ or ¼ in the avoirdupois system, would mean 8 ounces or 4 ounces, respectively, per 100 pounds of seed. By a fortunate quirk of numbers the standard dosage becomes instead of 2½ per cent by weight, 1 level teaspoonful per pound. With this as a unit of dosage, fractional measuring spoons may be used when lots of seed smaller than 1 pound are to be treated.

In working with seeds other than spinach, it was obvious that those which are bigger or lighter would require a different dosage from the standard. Dosage tests for many such plants have been attempted, but high relative emergence in the checks rendered many of them valueless. Data on beets, cucumbers, squash, peas, and lima beans appear in Table 5 and are shown graphically in Fig. 5.

For all of these large seeds, except beets, the optimum dosage lies near ¼ per cent, or 4 ounces per 100 pounds of seed. This approximates the 3 ounces per bushel frequently recommended for dusts on seed. However, it is only one-tenth as much as the standard dosage that was calculated for spinach. The lower dosage required is to be explained largely by the smaller surface exposed in a pound of pea seed than in a pound of spinach seed. For beets, however, the optimum dosage apparently is near 6 per cent, more than twice as much as for the smaller seed. At least three factors are involved in the high dosage requirement, *viz.*, (1) high volume per pound of seed, (2) extreme irregularity of seed which increases the surface, and (3) a big load of fungous material carried in the crevices of the seed. Based on our experience, this high dosage should be halved when the seed is to go into dry soil such as that which prevailed in 1933 in New York State, because in that year there was injury in one beet field.

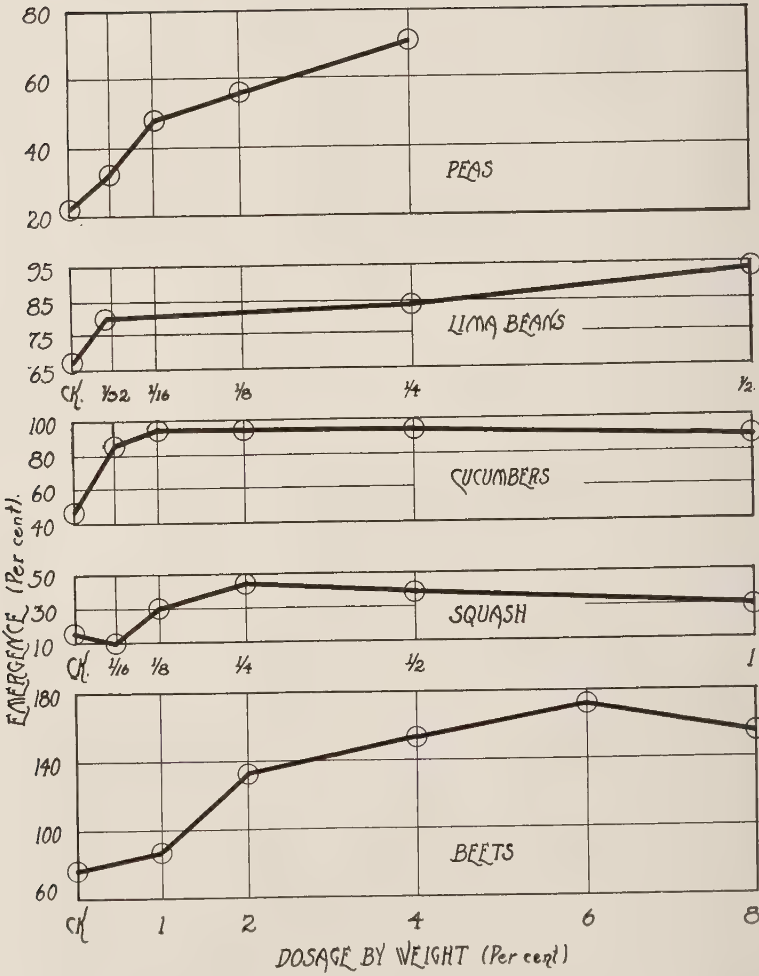

FIG. 5.—THE EFFECT OF DOSAGE OF RED COPPER OXIDE ON STAND OF VARIOUS VEGETABLES.

INJURIOUSNESS OF RED COPPER OXIDE

Red copper oxide is sometimes injurious to seeds. With some seeds it seems to be toxic occasionally and nontoxic at other times. A few observations regarding the conditions governing this toxicity indicate that as much care as possible should be taken not to apply

an excess of the dust and that organic matter in the soil reduces the toxicity of the chemical, probably by removing immediately any soluble copper that may appear. Sandy soils generally are more conducive to injury than are heavy soils. Dr. C. M. Haenseler of the New Jersey Agricultural Experiment Station stated in conversa-

TABLE 5.— EFFECT OF DOSAGE WITH RED COPPER OXIDE ON EMERGENCE OF VARIOUS VEGETABLES AND ON THE CONTROL OF POST-EMERGENCE DAMPING-OFF IN THE GREENHOUSE, ALL DATA EXPRESSED IN PERCENTAGE.

TREATMENT*	EMERGENCE, PER CENT	POST-EMERGENCE DAMPING-OFF, PER CENT
	Detroit Dark Red Beets†	
Untreated	77.7	27.9
1 to 100	87.4	17.9
2 to 100	132.4	11.3
4 to 100	153.0	4.6
6 to 100	172.0	1.9
8 to 100	155.7	3.2
	Early Fortune Cucumbers†	
Untreated	46.7	23.2
1/16 to 100	85.8	10.7
1/8 to 100	93.3	4.5
1/4 to 100	94.2	0.0
1/2 to 100	93.3	4.5
1 to 100	90.8	3.7
	Boston Marrow Squash†	
Untreated	15.3	10.0
1/16 to 100	9.7	0.0
1/8 to 100	30.6	0.0
1/4 to 100	43.1	0.0
1/2 to 100	38.9	0.0
1 to 100	27.8	0.0
	Henderson's Bush Lima Beans‡	
Untreated	66.0	....
1/10 to 100	80.0	....
1/4 to 100	84.0	....
1/2 to 100	94.0	....
	Perfection Peas§	
Untreated	22.5	....
1/32 to 100	32.0	....
1/16 to 100	48.0	....
1/8 to 100	56.8	....
1/4 to 100	71.4	....

* Fractions of a pound are given for ease in converting to ounces when more convenient.
† 6 replications.
‡ 2 replications.
§ 5 replications.

tion that in a few cases in that state tomatoes, eggplants and peppers were severely injured by red copper oxide when treated seed were planted in sandy seed beds which contained little or no organic matter. Likewise, Dr. R. S. Kirby of Pennsylvania State College reported that treated seeds were severely injured when planted in a clay soil excavated from the bottom of a cellar. The explanation in both cases probably is the low organic matter content of the soil.

Drought is highly conducive to injury. Soil from the single beet field where injury occurred was brought into the greenhouse and placed in a bed. When the soil was kept reasonably moist no injury occurred on beets even when a dosage of 8 per cent of red copper oxide was used, but marked injury occurred when the soil was kept dry for several days after planting even when a dosage of only 1 per cent was used. Acidity probably was not of importance in this injury as the soil tested pH 6.9 or nearly neutral.

Sweet pea seeds that had been soaked before treating and germinated in sand were excessively injured on Long Island and in Ithaca by red copper oxide. The young tap root was destroyed on the treated seedlings. Fortunately, a subsequent lateral grew downward and functioned as a tap root. When the seed was treated dry no injury was observed in soil or sand, and furthermore, the dry treated seeds germinated as rapidly as those that had been soaked.

APPARENT STIMULATION BY RED COPPER OXIDE

Evidence that red copper oxide sometimes accelerates the rate of emergence of tomatoes and spinach has been recorded in a previous paper,[9] while it had been shown elsewhere[10] that tomato seedlings from treated seed sometimes appear to grow taller than those from untreated seed. These reports have been substantiated reasonably well on a variety of plants, so that little doubt remains that occasionally seedlings treated with red copper oxide grow, or at least elongate, more rapidly than do untreated seedlings. Two lines of evidence support this view, as follows.

If elongation is really accelerated then emergence from the soil should be more rapid, since emergence is essentially an elongation process, especially if the seeds are fairly deep in the soil. The treated squash seedlings shown in Fig. 6 undoubtedly are emerging more rapidly than the untreated ones. Some information on

[9] Bul. No. 615 of this Station.

[10] Tech. Bul. No. 198 of this Station.

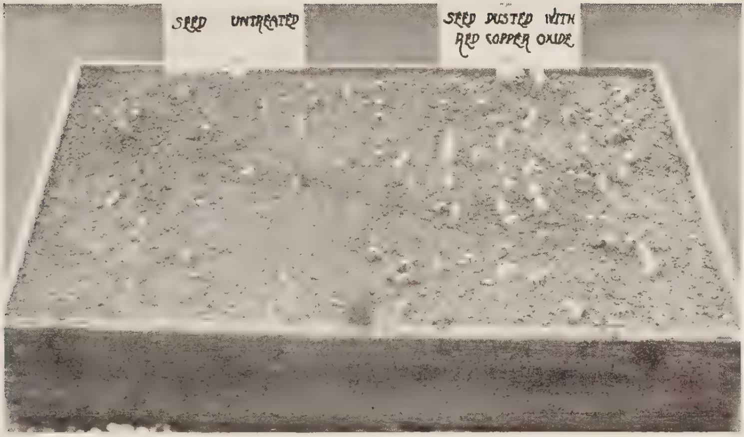

Fig. 6.—Accelerated Emergence of Squash Seedlings Resulting from Treating the Seed with Red Copper Oxide.

Left, 90 seeds untreated; right, 90 seeds treated. See No. 33, Table 2, Jan. 31, 1933.

accelerated emergence was obtained from the dosage test on cucumbers given in Table 5. The seeds were sown on October 17 and placed in a greenhouse held thermostatically at 18° C (64° F). A count was made on October 26 when they began to emerge. The final count of emergence made on November 3 is that which appears in Table 5. If the treatment accelerated the emergence of the cucumber seedlings, a larger proportion of the total number of seedlings should have come up by October 26, the date of the first count. The graph given in Fig. 7A shows that such was the case for the four smallest doses, *viz.*, 1/16, ⅛, ¼, and ½ per cent. The one per cent dose delayed emergence in this test. Figure 7A shows also that the smaller the dose, the greater the acceleration in terms of total emergence.

Data from another source throw light on this question of accelerated emergence. During the past year a large number of seed treatment tests have been made comparing different commercial samples of red copper oxide with a standard sample and a check, using Perfection peas as an index plant. The seeds for all tests were planted at a uniform depth of 2 inches and germinated under conditions of constant temperature and soil moisture, the latter regu-

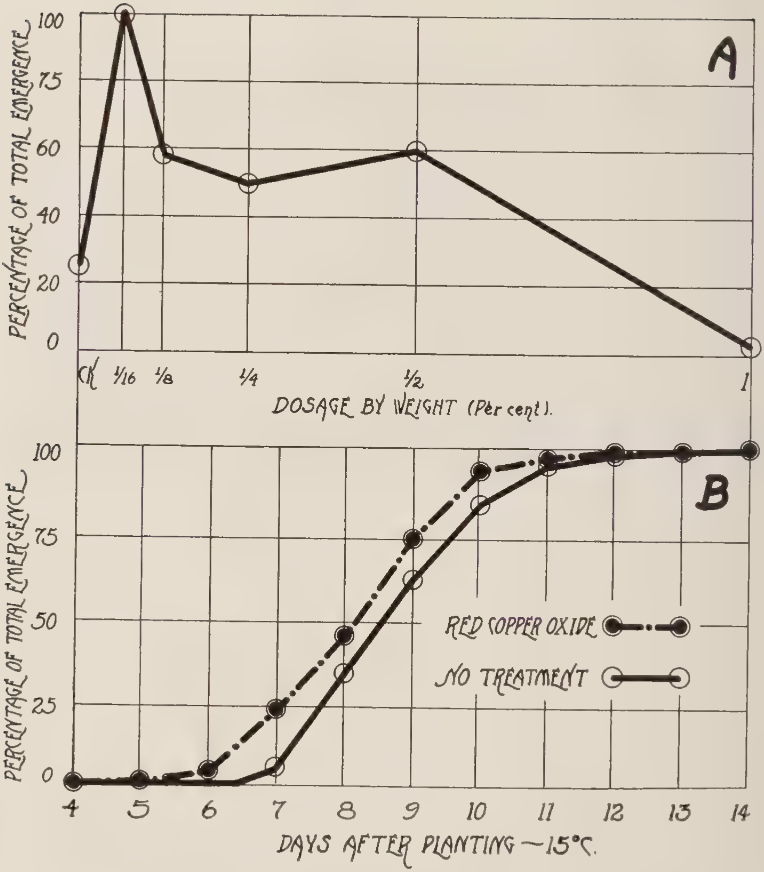

Fig. 7.—Accelerated Emergence of Seedlings Due to Treatment with Red Copper Oxide.

A, cucumbers. The smaller the dosage, the greater the acceleration of emergence as shown by counts on the first day that seedlings appeared. The highest dosage, *viz.*, 1 per cent, caused some retardation, however. B, peas. Accelerated emergence at 15°C (59°F) and nearly saturated soil.

lated by especially designed porous-pot auto-irrigators. If the emergence of pea seedlings were accelerated, data from these tests should reveal it. Accordingly, averages were calculated from 10 tests of the standard sample of red copper oxide and a check. The dosage was 1/4 per cent, the temperature 15° C (59° F), *Pythium ultimum*

was uniformly present, and the soil was nearly saturated with moisture for all tests. The data are presented graphically in Fig. 7B, each point being the average from the 10 tests. As in the case of the cucumbers, the emergence on various days is calculated as the percentage of the total because of the marked differences in total emergence in favor of the treatment. Emergence was 60.8 per cent from the treated seed but only 42.4 per cent from the untreated. These data, obtained under standard controlled conditions, indicate that red copper oxide in suitable dosage will accelerate emergence of pea seeds from cold, wet soil infested with a damping-off fungus.

Gross visual observations of accelerated emergence are easily obscured by the fact that frequently *more* plants emerge as a result of the treatment and hence appear to emerge more rapidly. This objection may be overcome, however, by calculating the relative emergence figures in percentage as has been done.

The second line of evidence is obtained by measuring the length of emerged seedlings. In an experiment in the fall of 1933 treated tomatoes looked taller than did untreated plants. After 18 days from planting at 20° C (68° F), plants were pulled just as the first true leaf began to form and 200 random plants were weighed and grouped into size classes from which the weighted average height was calculated. Data presented in Table 6 show that the treated seedlings were without question taller than the untreated, but that the *fresh weight per plant was practically identical.* In this case the treated plants had elongated more rapidly than the untreated, but even here the response may have been due to lack of light among the crowded seedlings since the fresh weight was not appreciably affected. On the other hand, the seedlings had hardly had time to assimilate much dry weight and thus show differences in this respect.

TABLE 6.— EFFECT OF RED COPPER OXIDE AND COPPER CHROMATE SEED TREATMENTS ON STAND, POST-EMERGENCE DAMPING-OFF, WEIGHT, AND HEIGHT OF TOMATO SEEDLINGS.

Treatment	Number plants emerged per sq. ft.	Post-emergence damping-off, per cent	Averages	
			Height, cm	Green weight, gram
Untreated	245	24.7	7.76	0.348
Red copper oxide	473	2.0	10.47	0.333
Copper chromate	437	4.7	11.09	0.406

One other good instance came to light of accelerated elongation of treated squash seedlings. The 26 seedlings from the check and the 37 seedlings from the treated that came from 50 seeds sown were carefully measured. The average height in inches was 4.76 for the checks and 8.64 for the treated seedlings. The apparent stimulation in growth in this case cannot be ascribed to competition for light as the seeds were planted thinly.

In some cases, especially in the field, it has been objected that treatment does not accelerate elongation; that such an appearance is only an optical illusion; that the treatment only increases the stand so that individual plants are propped up better by their neighbors and thus appear taller. In the case of the greenhouse test on beets listed in Table 2 under January 13, and illustrated in Fig. 1 this objection appeared to be valid. During the entire test the treated seedlings appeared taller than did the untreated. The plants were pulled on March 13 when they were 2 months old and grouped into height classes from which weighted averages could be calculated. Fresh and dry weight determinations were also made. Data presented in Table 7 indicate that at 2 months of age the treated plants were no taller than the checks. No doubt they were propped up better and only appeared taller than the checks. Perhaps at 23 days of age as in the case of tomatoes, the treated beets were taller than the checks, but being so thickly spaced they did not grow normally as shown by the fact that each check plant was nearly twice as heavy as each treated plant. Differences in stand show up prominently, however, when the weight data are expressed on the basis of unit row length.

Another "stimulating" effect of the red copper oxide seed treatment has been to deepen the color of many treated plants in the greenhouse and field. This has been observed several times on spinach in the field by the writers and by growers and canners. Canners, particularly, have expressed an interest in this phenomenon because the dark green color is a quality factor that they seek.

The simplest explanation for the cases of accelerated elongation or deeper green color in treated plants is that the roots are freer of disease and hence better able to function normally than those on untreated plants. In that case the apparent stimulation of the treated plants is only a normal situation, whereas the checks are really stunted by disease on the roots. This explanation is supported further by the fact that formaldehyde soil sterilization sometimes gives

TABLE 7.— EFFECT OF RED COPPER OXIDE SEED TREATMENT ON STAND, POST-EMERGENCE DAMPING-OFF, HEIGHT AND WEIGHT OF BEETS IN GREENHOUSE.

5-FOOT ROW, SECTION NO.	NUMBER PLANTS EMERGED*	POST-EMERGENCE DAMPING-OFF, PER CENT	LESS THAN 7 INCHES		7 TO 9 INCHES		9 TO 11 INCHES		11 INCHES OR MORE		NUMBER PLANTS HARVESTED†	AVERAGES		
			Number	Weight, grams	Number	Weight, grams	Number	Weight, grams	Number	Weight, grams		Height, inches	Green weight, grams	Dry weight, grams
NO TREATMENT														
1	84	13.1	26	72	23	311	6	127	2	61	57	8.44	571	37.0
2	82	7.3	9	39	25	305	16	372	7	220	57	9.74	936	62.0
3	64	15.6	16	80	12	141	11	220	14	557	53	9.87	998	33.5
4	51	13.7	13	33	15	121	9	156	8	181	45	9.52	491	30.5
5	62	14.5	16	85	6	73	17	305	8	219	47	9.72	682	37.0
6	40	30.0	5	17	9	103	3	59	7	241	24	10.00	420	33.5
Av. per section	62.9	14.4	......	......	......	......	......	......	......	......	47.1	......	683	38.9
Av. per plant	......	......	......	......	......	......	......	......	......	......	......	9.55	14.50	0.90
RED COPPER OXIDE, 2½ TO 100														
1	219	0.5	113	214	72	461	37	462	5	98	227	8.43	1,235	70.0
2	158	0.0	40	152	35	240	49	510	21	387	145	9.70	1,289	78.0
3	201	0.5	58	95	56	324	48	584	28	609	190	9.48	1,612	99.0
4	192	0.0	96	189	74	486	41	501	8	157	219	8.64	1,333	77.0
5	173	0.6	69	136	46	303	48	563	18	312	181	9.17	1,314	75.0
6	182	1.5	70	188	41	291	44	583	26	522	181	9.29	1,584	92.0
Av. per section	187.5	0.4	......	......	......	......	......	......	......	......	190.6	......	1,394	81.8
Av. per plant	......	......	......	......	......	......	......	......	......	......	......	9.12	7.3	0.43

* Shows post-emergence damping-off prior to January 22.
† Data taken March 13, 1933. Indicates that many plants disappeared between January 22 and March 23 in the untreated but not in the treated rows.

a similar appearance. The question of copper deficiency in the soil also arises. It has been suggested that the apparent stimulation is a response to copper as a nutritional element, altho Raber[11] believes that copper in plants should be considered more as a luxury than as a necessity.

TENTATIVE SPECIFICATIONS FOR RED COPPER OXIDE

In industry red copper oxide finds its major use in paints and has not been manufactured previously as a fungicide. Consequently, certain precautions must be observed in purchasing it for the latter purpose. Many grades of red copper oxide are on the market. These range all the way from the dark, cheap, coarse copper scale made from blister copper to the highest grade with a bright, brick-red color totally free from undesirable grit. The purity ranges from above 96 per cent to 50 per cent or lower. Unfortunately, pure red copper oxide deteriorates rapidly by changing chemically from the red oxide to the black oxide of copper, a material apparently worthless as a seed treatment fungicide.

Chemists have found, however, that the addition of a small quantity of oil will prevent this blackening and loss of potency, but usually this oil prevents the material from fuming, thus reducing its "dustability" or covering capacity and its adherence qualities, and in turn its fungicidal value. This oil, of course, does not affect the value of the material as an ingredient of paint. The presence of too much oil does not eliminate the value of the material as a fungicide, or else it would never have been adopted as widely as it has for seed treatment. Oily samples that clump together should not be chosen for such purposes, however, as samples that are dustable despite the presence of a minute quantity of oil have been produced. These are now obtainable on the market and should be requested when ordering.

In order to assist users, certain tentative specifications have been evolved for an ideal grade of red copper oxide for treating seeds. Let this be emphasized, however, that these are in the nature of preliminary specifications and may have to be changed from time to time as more is learned concerning this material and its use as a

[11] Raber, Oran. Nutritive and stimulative functions of salts, copper. *Principles of Plant Physiology. 1933.* (Page 109.)

fungicide. Additional research is needed and is being carried out to enable manufacturers to make a material meeting the following specifications:

1. The material should contain not less than 96 per cent of cuprous oxide (red copper oxide). A measure of purity.
2. The color should be bright red, approximating carmen (according to Ridgway's Color Standards). A further measure of purity.
3. The color should not change on standing even when the material is exposed to the air. A measure of stability.
4. When passed dry thru a 325-mesh screen, there should remain on the screen not more than 2½ per cent by weight of coarse particles. A measure of fineness.
5. The material should be fluffy, should flow smoothly, and fume or smoke when shaken up in a vial, and it should not collect into lumps under these conditions. A measure of dustability.
6. If a small amount of the material is placed on white paper which is then slowly changed to a vertical position, the paper should retain sufficient dust to remain bright red in color. A measure of adherence.

The writers will be glad to assist any one who has difficulty in obtaining suitable material. Retail outlets are not yet widely established, but reputable seed houses are stocking red copper oxide for distribution. Local drug stores generally will handle it, but frequently their stock has been allowed to deteriorate and become blackened. Also retail dealers in spray materials will usually arrange to sell it, but they should be reminded of the specifications necessary.

USING RED COPPER OXIDE IN PRACTICE

In using red copper oxide in practice growers have raised a number of questions as to methods. First of all, one advantage is that it may be used dry and thus avoid the messiness of liquid dips. Directions for using red copper oxide are simple. A standard dosage of 2½ pounds of dust per 100 pounds of seed has been suggested, but some observers consider that excessive. For small quantities of seed this dosage is equivalent to 1 level teaspoonful per pound. The 2½ per cent dosage is satisfactory for seeds the size of spinach or smaller and for rough, light seeds like beets or chard. For larger or heavier seeds like peas, squash, or cucumber, ½ to ¼ per cent is sufficient. This is 1/10 of the standard dosage, which would be a half teaspoonful per 5 pounds or 1 teaspoonful per 10

pounds. For packet seeds, dosage regulation is not always feasible and is not important for those seeds that are not injured by excess dosages, but even for these a smaller quantity than the maximum that will adhere is desirable. If the quantity of seeds to be dusted is not too small, a set of fractional measuring spoons is well worth while to avoid using an excess of dust that might delay emergence.

Having determined the dosage, the necessary quantity of chemical is added to the seed in a tight container, which should not be filled more than half full: "SHAKE WELL BEFORE USING" is just as apt for this medicine as for those kept in the bathroom cabinet. A complete coating of chemical around each seed is necessary if it is to be "galvanized" against rotting in the soil.

The question of holding treated seeds in storage has been raised and is of considerable importance if canners and seedsmen are to treat seeds before release. Some tests have been made in this connection. Seeds of cabbage, beets, carrot, cauliflower, cucumbers, peas, spinach, tomato, calendula, cosmos, hollyhock, and lupine, when treated with a non-darkening grade of red copper oxide, have been held in the office as long as 10 months without apparent injury and without loss in effectiveness of the chemical. Perhaps storage under other conditions, particularly under moist conditions, might result in injury.

The question of using red copper oxide on seeds that had been treated with other chemicals has arisen, but there is no specific information on this subject as yet. If liquid treatments, such as corrosive sublimate are to be used, they should be applied first and the seed allowed to dry. Then, red copper oxide could probably be applied with safety. If the seeds are not dried first, too much chemical will adhere and injury may occur as in the case of the sweet peas soaked before treating.

Growers have inquired as to whether red copper oxide may not be substituted for some of the treatments now in vogue for controlling seed-borne fungi. In popular articles some writers have referred to it as a seed disinfectant. Undoubtedly it does have an effect in killing seed-borne fungi, but as understood at present, its main effect is to protect the seed from decay by soil-borne organisms. Its possibilities for disinfecting seed or as a substitute for treatments now employed for black rot of crucifers, celery blights, angular leaf spot of cucurbits, bacterial canker of tomato, and the like have not been tested.

Red copper oxide should not be confused with red iron oxide which would be worthless as a fungicide nor with red or yellow mercury oxide which are injurious to some vegetable seeds at least.

SUMMARY

1. The range of red copper oxide as a seed treatment for controlling damping-off of 107 species and varieties of plants, its injuriousness, and its apparent stimulating effects have been studied.
2. The chemical is at least partly effective against *Rhizoctonia solani,* altho probably the main effect is on *Pythium ultimum.*
3. The following plants responded favorably under one or more of the conditions of these tests: Arabis, calendula, centaurea, cobaea, cockscomb, cosmos, didiscus, eschscholtzia, gilia, gypsophila, helichrysum, heliopsis, heliotrope, larkspur, leptosiphon, lupine, marigold, mesembryanthemum, nemesia, nasturtium, pansy, penstemon, petunia, phacelia, phlox, pyrethrum, salpiglossis, salvia, snapdragon, stock, sweet pea, viola, verbena, garden beet, sugar beet, cabbage, carrot, cauliflower, celery, chard, cucumber, eggplant, endive, escarolle, lettuce, melon, peas, pepper, radish, romaine, salsify, spinach, squash, and tomato.
4. Legumes, crucifers, dianthus, agrostemma, aubrietia, chrysanthemum, clarkia, dimorphotheca, gaillardia, hibiscus, petunia, and zinnia show a tendency toward injury and should be treated with caution.
5. Onions, leeks, chives, and corn responded poorly or were injured.
6. Red copper oxide seems to be as effective in most cases as any material available, and more effective in some cases.
7. Dosage for most seeds should be 2½ per cent by weight or 1 level teaspoonful per pound. The dosage for big seeds like peas or cucumbers should be ¼ to ½ per cent or 1/10 teaspoonful per pound. Six per cent is the optimum for beets, but this dosage should be halved for sowing in dry soil.
8. Low organic matter content in the soil, such as would occur in sand; drought; or presoaking of the seed before treatment may result in injury.
9. In some cases red copper oxide gives an apparent stimulation to seedlings causing them to emerge and elongate more

rapidly than the checks. It may also deepen the green color as sometimes occurs in spinach. These reactions may be due only to disease control, however.

10. In practice the dosage should be regulated and seeds should be shaken dry with the dust in a tight container until each seed is completely coated so that it will be protected from rotting in the soil.
11. Treated seeds may be held for any reasonable length of time in dry storage without injury.
12. No information is available on substituting red copper oxide for corrosive sublimate for controlling seed-borne diseases.
13. Tentative specifications are given for purchasing red copper oxide as a fungicide.

INDEX TO COMMON AND TECHNICAL NAMES OF PLANTS TESTED [12]

The plants are listed in the text under the names thought to be best known to the trade. The correct technical names are given in this index for convenience in reference. Numbers in roman type indicate page references; numbers in bold face type indicate tables and items in tables, as for example, **3/3** indicates Table 3, item 3—beets, garden.

[12] Acknowledgment is made to G. P. Van Esltine, systematic botanist of this Station, for assistance in preparing this index.